RECOVERY OF BURIED INDUSTRIAL WASTES AND AQUIFER REHABILITATION AND MONITORING AT OLIPHANT, BRUCE COUNTY

VOLUME 1

MARCH, 1984

Ministry
of the
Environment
Ontario

ONTARIO MINISTRY OF THE ENVIRONMENT

RECOVERY OF BURIED INDUSTRIAL WASTES AND AQUIFER REHABILITATION AND MONITORING AT OLIPHANT, BRUCE COUNTY

VOLUME I

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March, 1984

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*NOTE

Due to the length of the Appendices, they are printed separately as Volume II which is available in the Ministry of the Environment Southwestern Regional Office in London, Ontario, Canada.

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DISCLAIMER

The investigations carried out by the Ministry of the Environment which are described in this report were done partly on the basis of personal field observations and investigations by Ministry staff, including test pits and test drilling programs, results of soil and water samples analyses and their interpretation, etc. and partly on the basis of information about past events obtained from a number of sources. Not all of the information about past events has been independently verified and some of it may be subject to dispute. The information is included not for its absolute accuracy but for the purposes of explaining the basis for certain studies carried out by the Ministry. Some of the information in this report is of a nature that would be considered "heresay" in legal proceedings and no implication of legal liability should be drawn from such information.

SUMMARY

The recovery of industrial wastes and an aquifer clean-up operation were carried out at Oliphant during the summer and late fall of 1983. A total of 228 45 gallon drums containing metallic grinding sludge and paint solvent were recovered from the Frank Field sand pit. They were reportedly buried in 1977. The pit was not then, nor has it ever been an approved waste disposal site.

A magnetometer survey of the local area of suspected buried wastes proved to be a very useful tool in delineating the area of steel drums and metallic grinding dust.

The clean-up operation consisted of the removal of waste and contaminated soil by means of excavation and pumpage of contaminated groundwater by means of vacuuming.

Hydrogeologically, the Field pit area is considered to be quite vulnerable to contamination. It is underlain by the surficial fine to medium sand up to 7 m thick which in turn is underlain by 1 metre of weathered silt till. The surficial granular deposits are saturated with an average depth to water table of 2 m and groundwater flow in the Field sand pit area is in the westerly direction. The surficial deposits are underlain by fractured dolostone, the source of water supply for many wells in the area. Several local residents and cottages rely on sand points for water supply which utilize water table aquifer.

In all cases, liquid portion of waste found in the drums and a few of the 17 drums containing paint solvent waste seeped into the subsurface. The clean-up operation and the subsequent groundwater quality monitoring revealed

that the contamination plume was confined beneath and to a short distance due west from the buried wastes. Based on the available information collected so far (22 observation wells installed and monitored), it does not appear that buried wastes impaired water quality outside of the Field sand pit. The water quality monitoring program will continue.

INTRODUCTION

This report summarizes the results of an investigation of buried drums containing solid and liquid industrial wastes, the removal and the general clean-up operation and water quality monitoring in the Oliphant area.

Objective of Study

The main objectives of the study were: (a) to outline the area of the buried industrial waste and to arrive at an effective means of waste removal, (b) establish the extent of groundwater contamination, (c) carry out effective clean-up operation and aquifer rehabilitation, (d) establish necessity for long-term water quality monitoring.

Background

Mr. Frank Field owns a piece of property located in Lot 10 Range South, Amabel Township, Bruce County, (Figures 1 and 2, Photo 1). A portion of this property includes a sand pit from which sand is extracted and sold by the owner mainly to the local road authorities.

In late April, 1983 Mr. Field complained to the local health authority about an undesirable taste and odour experienced in his drinking water. The odour was described by Mr. Field as similar to paint thinner. At that time, the source of water supply, a sand point approximately 2.5 m deep, was located at the back and approximately 40 m south of the house in the sand pit. Subsequently, Mr. Field relocated his sand point placing it approximately 35 m north and in front of the house. Reportedly, this sand point is also 2.5 m deep and it is presently used as the source of water supply for the Field household.

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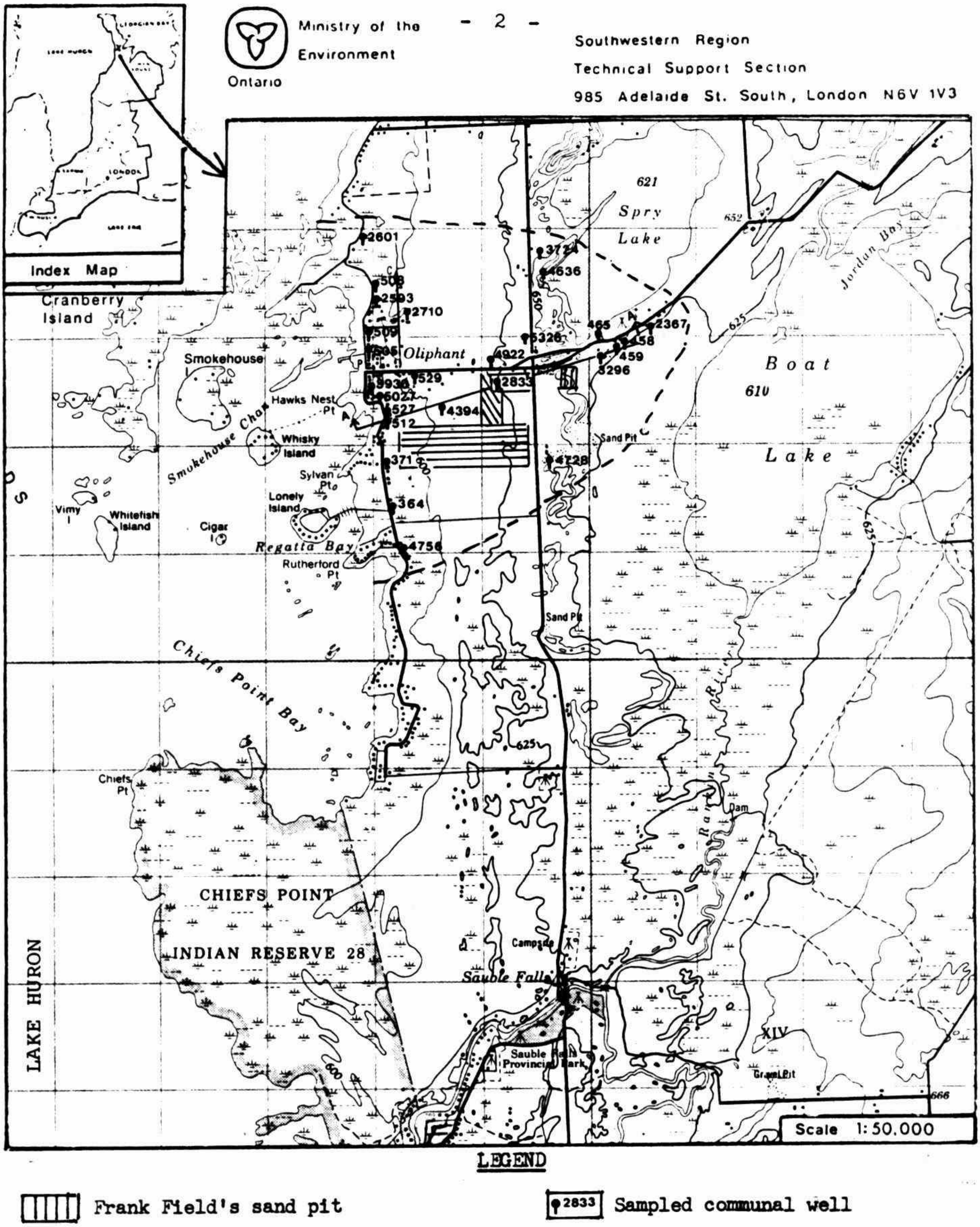


LEGEND

- Frank Field's sand pit
- Camidge-Collins Subdivision (approved)
- Winskill Subdivision (proposed)
- 364 Bedrock well; record on file with MOE (selected)
- 2833 Sampled communal well
- A Line of cross-section
- Area searched for water well records on file with MOE

Figure 1. Location map.

Photo 1. Aerial view of the Frank Field sand pit (centre of the photo) and the surrounding area. (Photo taken on May 5, 1983 by Ron Johnson)

Photo 2. Looking east at the eastern edge of the sand pit, two green drums are partially covered with sand. The third drum is partially behind the tree (centre). These drums had been dug up during the spring of 1983 and dumped in this area. (Photo taken on May 4, 1983 by Jim McRorie)

The complaint of Mr. Field was referred to the Ontario Ministry of the Environment's (MOE) District Office in Owen Sound by the local Health Unit. Subsequently, the MOE staff obtained the initial water samples from the present Field sand point on April 26, 1983. The original sand point had been removed and no background water quality was obtained from the sand point while it experienced the undesirable taste and odour.

The initial field work by the staff of the Technical Support Section of the London Regional Office of the MOE was carried out on May 4 and 5, 1983. According to Mr. Field, in early spring of 1983, while he was regrading the floor of his sand pit, he recovered several 45-gallon drums. Without paying too much attention to it, they were pushed to the eastern margin of the pit together with other unusable material such as top soil, tree stumps, and some brush. The drums were subsequently partially covered with soil and sand materials (Photo 2).

On May 4, 1983 Mr. Field indicated to the MOE staff that he suspected that there were still a number of drums buried in the middle of the pit. On that day, utilizing his backhoe, a few drums containing metallic grinding waste were partially revealed with their tops lying a few tens of centimeters below the pit floor (Photo 3).

Location

The subject area is located 10 km west of the Town of Wiarton in Lot 10 Range South, Amabel Township, Bruce County (Figure 1). More precisely, the Field sand pit is located 350 m east of the intersection of Bruce County Road Nos. 13 and 21 and 60 m south of Bruce County Road No. 13 (Figures 1 and 2). The access to the sand pit in question is from County Road No. 13 (Figure 2).

Topography

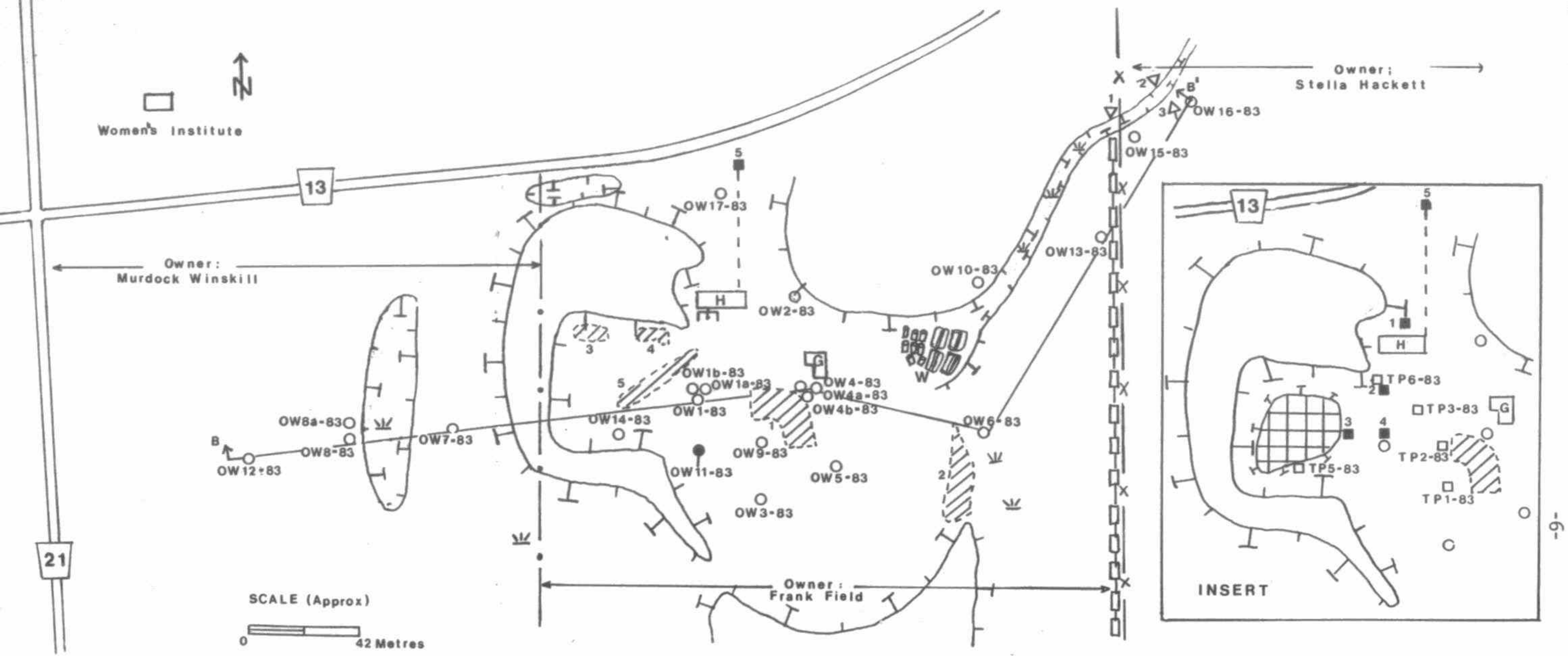
The general area around the pit is typically hummocky consisting of sand dunes up to 10 m high. The prevailing orientation of this system of sand dunes is in the north-south direction. They are concentrated in a band 1.6 to 2 km east of the Lake Huron shore.

The area of intensive investigation is located in an active sand pit where the original north-south oriented dune is partially levelled to the general elevation of the surrounding land.

Drainage

Topographically, the study area belongs to three different local catchments, namely (a) Lake Huron, (b) Spry Lake and (c) Boat Lake. Water originating from precipitation infiltrates sand quite rapidly in the central northern and the western portions of the intensive study area (Figure 2). Only during the early spring after rapid snow melt and intensive rainfall and in the late fall, the local swales may become temporarily filled with water. This situation may be the result of: (a) high water table which is temporarily reflected by water level in these swales, or (b) infiltration being slowed down by a layer of leaves and other organic matter accumulated at the bottom of these swales (perched water condition).

In particular, the northeastern and eastern portion of the Field property (Figure 2, Photo 1) where the permeability of surficial deposits is moderate may stay wet until the summer months. Significantly, there is a defined surface water drainage which originates a few tens of metres east of the Field garage as a low swampy area (Photo 1, and Figure 2). This area is virtually dry during the summer and



*As existed in summer-late fall, 1983

LEGEND

OW3-83 ○, ● Observation well with ident. number (overburden, Bedrock)
TP1-83 □ Test pit with indentification number
4 ■, ■ Former and present location of sand point - supplying F. Field residence
3 ▽ ▽ Sampled surface water and runoff
1 Clean-up area
W Stockpile of empty drums, empty engine oil containers and derelict vehicles
Stockpile of top soil (May, 1983)
X—X—X Property boundary (unmarked, wire and stone fence)
Occasionally wet area
H Frank Field residence
Septic tiles
B B' Line of cross-section

Figure 2. Map detailing the area of investigation and showing field installations.*

fall, but it becomes covered with water during the winter and spring. It extends to the northeast onto the Hackett property, where it becomes a defined ditch, which then flows into roadside ditch. This ditch further flows through the culvert beneath County Road 13 to the north side of the road where it eventually empties into Spry Lake less than one hundred metres from the road.

Previous Investigations

No special investigations were carried out at the actual sand pit in question by other workers. However, the Paleozoic geology of the Bruce Peninsula including the study area was described by Liberty and Bolton (1971). The Quaternary geology of the Wiarton map sheet including the study area was described by Sharpe and Jamieson (1982).

Two reports by Paragon Engineering Ltd. (1979 and 1983) describe the local geology and provide a detailed account of two pumping tests carried out in connection with two proposed subdivisions. These developments are located approximately 1 km west of the Field sand pit.

Field Work

The field investigation and water quality monitoring was carried out by MOE staff, Southwestern Region. This work commenced on May 4, 1983. Among other things, the field work included:

1. Field and airborne reconnaissance survey of the local area including an interview with the sand pit owner, Mr. Field and a few other local residents.

2. Geophysical survey of the sand pit with an attempt to delineate the area of the buried wastes.

3. Test drilling, test pits excavation, and the installation of observation wells by means of drilling and by using backhoe, etc.

4. Development and sampling of observation wells, surface water and domestic water wells for qualitative analyses.

5. Levelling survey including establishing collar elevation for each observation well.

6. Periodic water level measurements in each observation well and collection of split-spoon samples for mechanical analyses.

7. Clean-up operation including removal of drums of buried wastes, contaminated sand and pumping and removal of contaminated water.

Field Installations

In order to assess the geological and groundwater conditions on the site and its immediate vicinity, and also help to establish the extent of groundwater contamination a borehole drilling program was undertaken. It also included excavation of test pits using a backhoe.

A total of 22 observation wells were constructed using the following methods.

1. Observation wells (OW1-83, OW2-83, OW3-83, OW4-83, OW5-83 and OW9-83) were constructed using a backhoe.

2. Observation wells (OW7-83, OW8-83, OW10-83, OW12-83 and OW13-83) were constructed using a hand-held solid stem power auger.

Photo 3. A close up of the drum uncovered beneath 15 cm of sand from the floor of the sand pit approximately 15 m southwest of the garage. The drum was ripped open by the front-end loader during the removal of sand cover. The orange and black solid metallic waste contained in the drum was revealed. (Photo taken on May 4, 1983 by Jim McRorie)

Photo 4. Looking north, the commencement of the cleanup operation is shown. The first drum which contained liquid industrial waste is to the left of the rubber-tired front end-loader. (Photo taken on June 16, 1983)

3. Observation well (OW11-83) was constructed by a water well drilling contractor using a mud and air rotary drilling rig.

4. Observation wells (OW1a-83, OW1b-83, OW4a-83, OW4b-83, OW8a-83, OW14-83, OW15-83, OW16-83 and OW17-83) were installed by a truck-mounted, continuous flight, hollow stem power auger.

In the latter case, 0.61 m-split spoon samples were taken at least at every 1.5 m interval for soil examination. Samples were taken at selected intervals for further examination in the laboratory and for mechanical analyses.

In each test hole a simple piezometer was constructed using 3.81 cm diameter ABS pipe with a 0.3 to 0.6 m slotted (hacksawed) section at the bottom, wrapped with fiberglass cloth; a plastic cap was also attached at the bottom of the pipe. After the piezometer was in place, the hollow stem auger was pulled, thus allowing native material to collapse around the ABS pipe. Borehole (observation well) depths constructed into the overburden varied between 1.4 m and 7 m, with five boreholes drilled to the top of the bedrock. Only OW11-83 was drilled into the bedrock with a total depth of 22.86 m (Appendix A).

GEOLOGY

The geology in the general and local area is illustrated in Figures 3, 4 and 5.

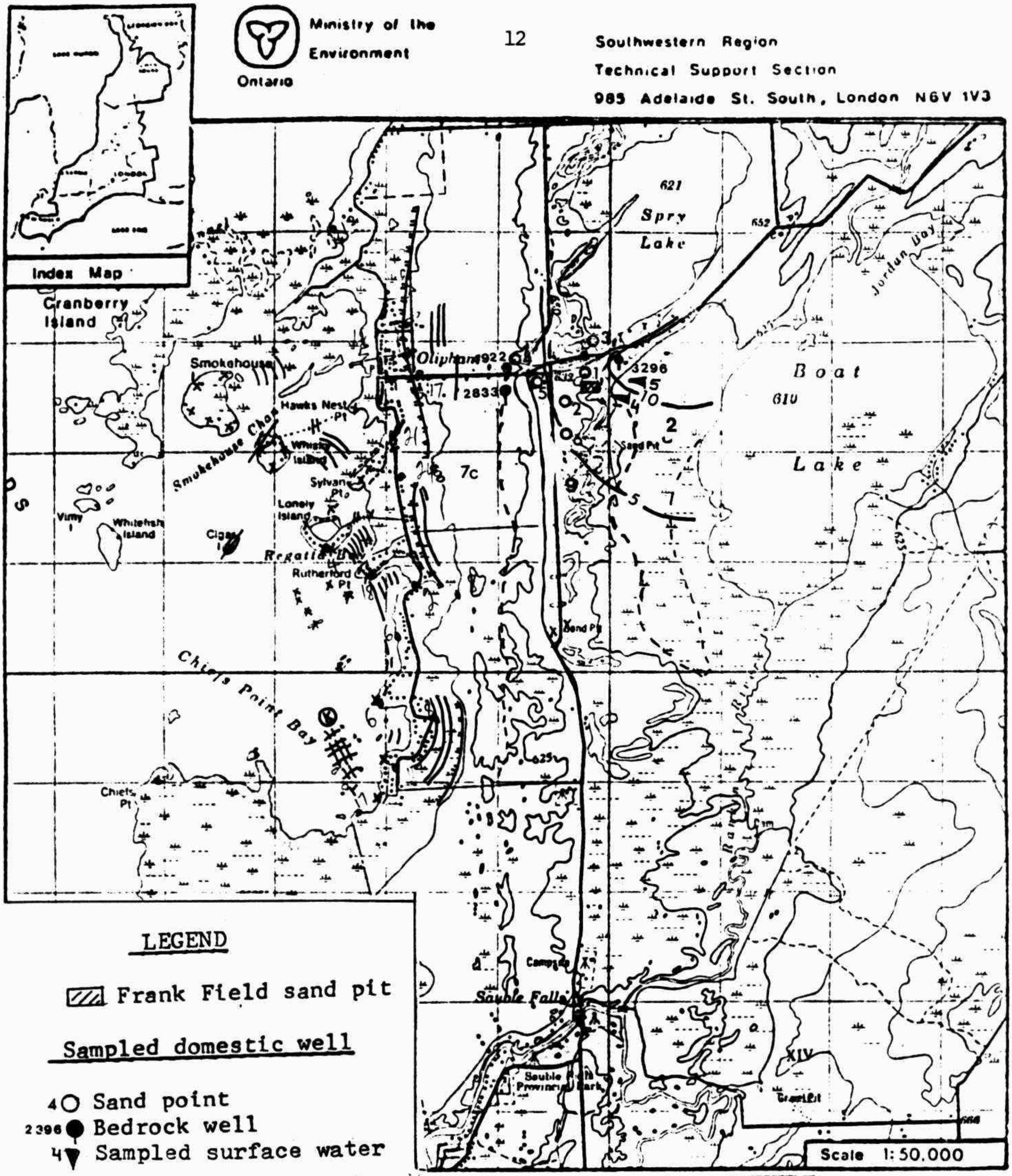
Bedrock Geology

The bedrock geology of the study area is described in Liberty and Bolton (1971). The Guelph Formation forms the bedrock in the study area. This formation consists of fine crystalline dolomite.

Surficial Deposits

The areal distribution of surficial deposits is illustrated in Figure 3, while their vertical stratigraphy is shown in Figures 4 and 5, respectively. Numerous boreholes and test pits constructed and excavated for the purpose of this study confirmed that the unconsolidated surficial sediments consist for the main part of rather uniform fine to medium grained sand relatively rich in organic matter (wood logs to finely divided state) or slightly gritty or pebbly at several horizons in the lower portion. The lowest organic-rich layer was encountered in several borings at the base of the sand sequence overlying glacial till unit (Figure 5).

Sharpe and Jamieson (1982) report on finding organic materials in similar sand sequence of shallow-water and windblown origin along the nearby Sauble River. The organic materials occur at elevations below the Lake Nippissing bluff in the area, and are radiocarbon-dated at 5300 to 4300 years B.P. These deposits record the Lake Nippissing transgression (rising lake levels) in the Huron basin burying and reworking lagoonal or fluvial sediments



LEGEND

Frank Field sand pit

Sampled domestic well

4 ○ Sand point

2396 ● Bedrock well

4 ▼ Sampled surface water

CENOZOIC

QUATERNARY

9	Aeolian and shallow liacustrine deposits: fine to medium sand
7c	Glaciolacustrine deposits: sand, gravel in beaches, bars, spits
2	Bruce till: stoney sandy silt

(Geology after Sharpe and Jamieson, 1982)

SYMBOLS

Abandoned shoreline

Abandoned shore bluff

Geological boundary (approximate)

Drift thickness contour in meters

Bedrock outcrop

Figure 3. Quanternary geology and drift thickness map.

relatively rich in organic matter (Feenstra, 1984). Windblown sand forms the upper portion of the sequence.

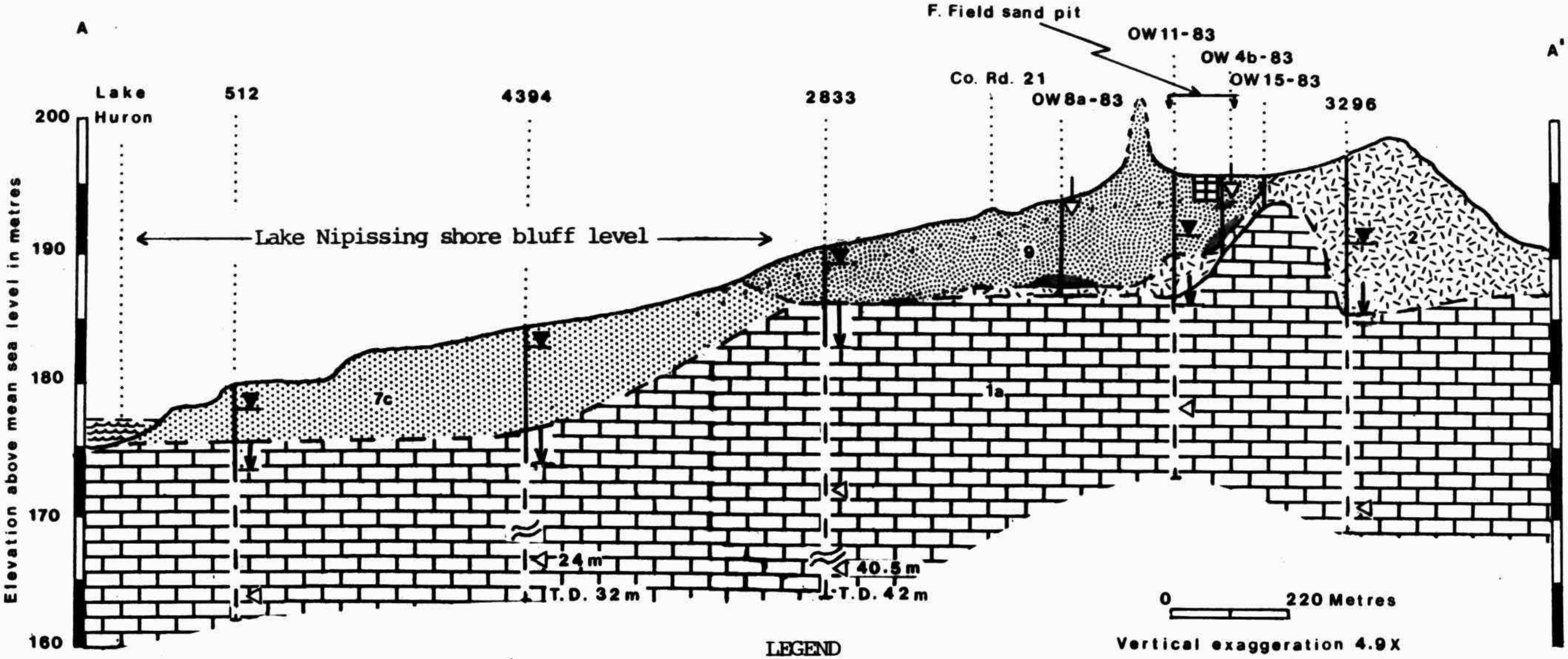
The lower-most unit of the unconsolidated sequence consists of till with silty and sandy matrix and up to one metre thick (FIgure 5; Bruce till of Sharpe and Jamieson, 1982). This deposit immediately overlies the carbonate bedrock.

The sands gradually "pinch out" towards the eastern margin of the Field property. Further east stoney, sandy silt Bruce till is found at ground surface (Figures 3 and 4).

Drift Thickness

Based on the information from water well records and from the boreholes, the thickness of the unconsolidated sediments in the general area varies between 1.4 m and 12 m (Figures 3 and 4). As illustrated in Figure 4, in general the bedrock surface topography slopes in the westerly direction towards Lake Huron. An exception to this is immediately east of the Field property where it appears that there is a bedrock topography with only 1.4 m of overburden.

Two boreholes (OW1b-83 and OW4b-83) encountered the bedrock at the Field sand pit at the depth of 6.5 m. However, the third borehole constructed into the bedrock (OW11-83) reported the bedrock at 8.5 m. Since there are no collar elevation differences for these three observation wells, there is a possibility that a minor bedrock "depression" exists in the southwestern section of the sand pit in question, but this has not been confirmed.



LEGEND

CENOZOIC

QUATERNARY

9 — Aeolian and shallow lacustrine deposits: fine to medium sand

7c — Glaciolacustrine deposits: sand, gravel

Organic layer: wood fragments and finer organic material in fine sands

2 — Bruce till: stoney sandy silt till

PALEOZOIC

SILURIAN

1a — Guelph Formation: dolostone

SYMBOLS

---- Geological boundary (inferred)

4395| Water well with record number

OW15-83| Observation well with id. number

↓ End of casing

◁ Depth water found

▼ ▽ Water level (Bedrock, overburden)

⊞ Removed industrial wastes

Figure 4. Cross-section A-A' illustrating regional geology and hydrogeology.

HYDROGEOLOGY

There are two distinct water bearing zones in the study area: fractured bedrock and fine to medium grained sand with intergranular porosity (Appendix C). Their hydrogeological characteristics are briefly discussed in the following paragraphs.

Bedrock Aquifer

The porous bedrock dolostone constitutes a fractured aquifer system and is the source of water for two communal wells and numerous domestic wells in the local area (Figure 1, and Appendix D).

The permeability of the bedrock formation is largely the result of solution weathering which is quite common in the carbonate rocks of the Bruce Peninsula (Cowell and Ford, 1980). Dolostone solution pavements are formed by surface runoff enhancing joint patterns to produce grikes (solution fissures). These features have been forming since glacial ice left the area about 12000 years ago.

The basic jointing and structure pattern was enhanced by stream erosion and weathering. Glacial ice was controlled by this bottom topography and glacial erosion enhanced the pre-existing weathering pattern.

Surficial Aquifer

Glaciolacustrine and aeolian deposits mainly consisting of fine to medium grained sand form the surficial (water table) aquifer. The thickness of this granular material in the study area may reach 6 m and the depth to water level generally varies bewteen 1 and 2.5 m. This largely depends on the topography and the time of the year when the water level measurement is made (Figure 5). As illustrated in Figure 6, there are significant water table

fluctuations throughout the year with the high water level occurring in late spring and the water level low occurring in October-November. This apparent dynamic equilibrium of water level largely depends on climatological conditions during the year.

Groundwater Use

Bedrock Aquifer

The bedrock aquifer system is utilized by many domestic wells in the area (Figure 1, Appendix D). There is also one communal well serving the Camidge-Collins subdivision which already has seven water line connections. A second communal well is to serve the proposed 38-lot Winskill subdivision. Both communal wells are located approximately 1 km west of the Field property and the details concerning their capacity and water quality are described by Paragon Engineering Ltd. (1979 and 1983).

It is worth noting that after the Cammidge-Collins subdivision well was recently deepened with an aim to increase its yield, a significantly high barium concentration (11 mg/L) was found in this well. This elevated concentration of barium is natural phenomenon associated with the water-bearing formation from which this well obtains water.

Surface Sand Aquifer

The surficial aquifer in the local area provides a water source for domestic use. Although there are no water well records for shallow wells in the study area (sand points) local field well inventory survey within a 0.5 km

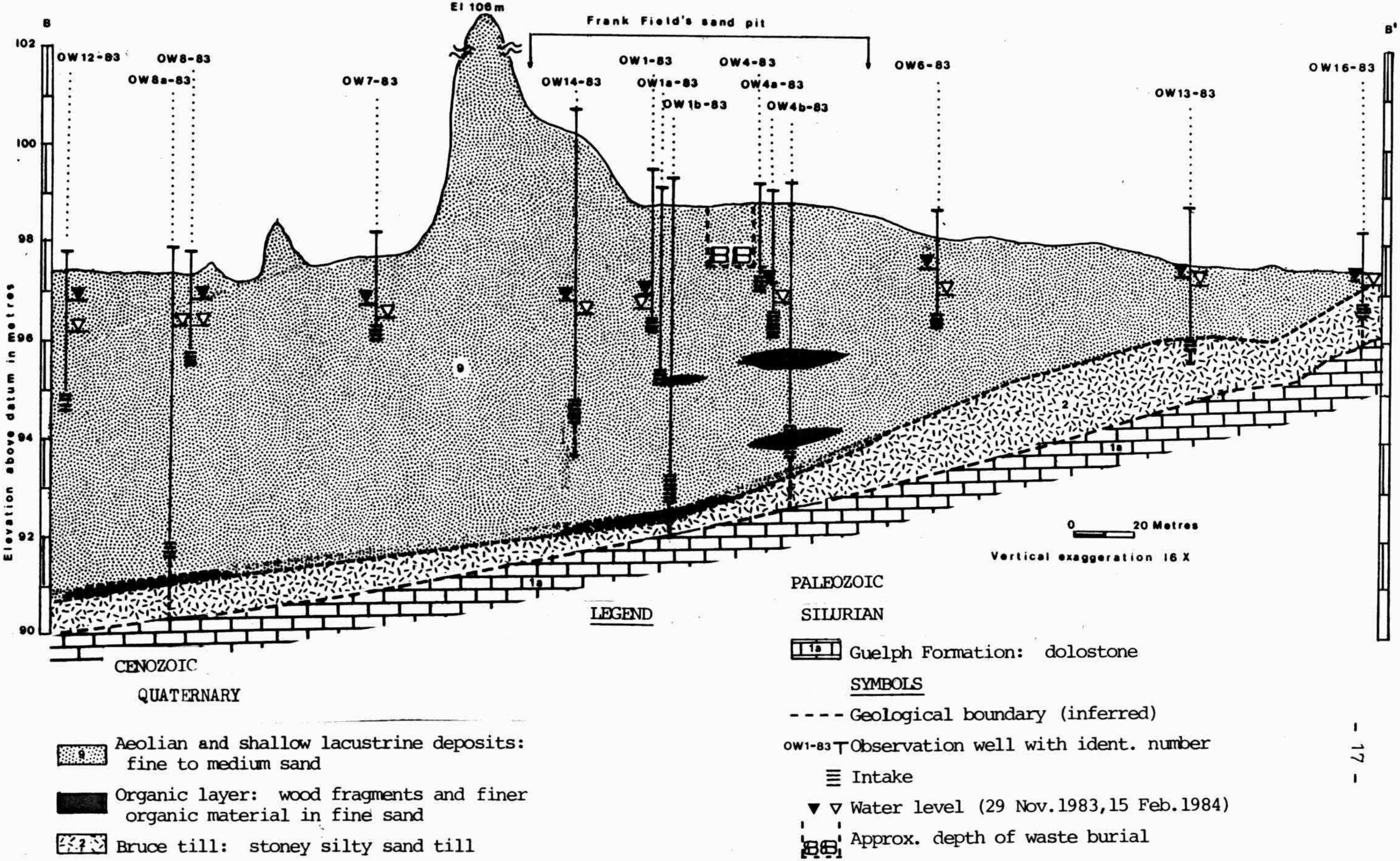


Figure 5. Cross-section B-B' illustrating local hydrogeology.

radius of the Field sand pit revealed that there were six sand points utilizing the sand aquifer (Figure 3, Appendix E). The depth of these sand points could not be measured, nevertheless, according to their owners they may reach 3 to 4 m in depth.

The Field Well Point

The nearest sand point to the Field sand pit and buried wastes is 2.4 m deep and approximately 50 m distance from the nearest area of buried barrels containing industrial waste (Figure 2). It is the source of domestic water supply for the Field family.

According to Mr. Frank Field, there were four previous locations of his well point; it was moved around because of the taste and odour problems. The present and former locations of the Field well point are indicated in Figure 2. Reportedly, its original location was in front of the Field residence, where it was used as the water source during the construction of the house in the fall of 1982. Due to a "swampy" taste, it was subsequently moved to its second location at the back of the Field residence (location 2, Insert in Figure 2).

It remained at this second location until approximately March or April, 1983 when it was relocated and placed at its third location, reportedly 15 m due west from the observation well 1 (OW1-83) (location 3 in Figure 2). Reportedly, this was done because of an undesirable odour in the water. Shortly after that, a paint thinner odour appeared again in the Field's tap which reportedly forced him to relocate it again at a fourth location wich approximately one meter from OW1-83. Approximately few weeks after that a paint thinner odour reappeared again necessitating to install a new well point at its present

location (Location 5 in Figure 2). About that time, Mr. Field complained about taste and odour problems in his drinking water to the local Health Unit which was subsequently referred to the MOE for further investigation.

Surface Water Resources

There are three lakes within a 2 km distance of the Field sand pit. Two of these lakes (Lake Huron and Spry Lake) are extensively used for recreational purposes, while Boat Lake has very limited access from the southeast side and, therefore, its recreational use is quite restricted.

Immediately south of the Field property, there is an intermittent wet area representing groundwater seepage. Periodically, this seepage produces an insignificant flow which moves in the easterly direction entering the swamp on the B. Patterson's property. Reportedly, during the summer and fall months cattle may drink this water on the Patterson property.

A small open ditch located on the Stella Hackett property adjacent and northeast of the Field property has intermittent flow emptying into Spry Lake. It originates in the northeastern section of the Field property. Presently, there is reportedly no use of this ditch water.

Groundwater Flow Systems

According to the information from water well records, groundwater flow in the bedrock aquifer is in the westerly direction with Lake Huron being the discharge area (Figure 4). Several bedrock water wells along the Lake Huron shore were reported flowing at the time of

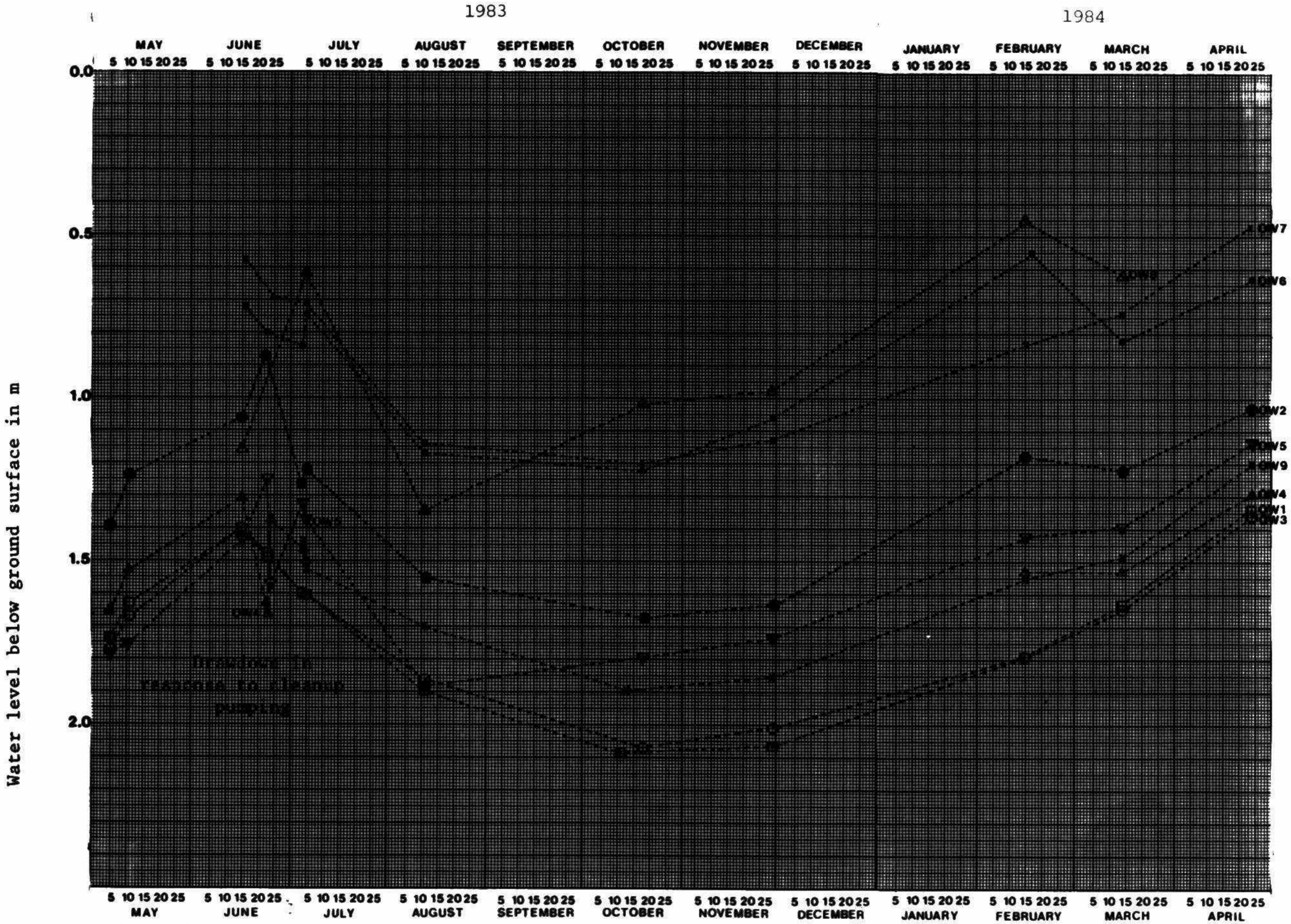


Figure 6. Groundwater level hydrographs for selected observation wells.

construction indicating that they are located in the discharge zone for the bedrock aquifer (Appendix D).

Measured water levels in the observation wells were used to delineate the water table configuration and thus identify the direction of groundwater flow.

Based on this information, there is a definite water table divide centered immediately east of the actual sand pit in question, but still on the Field property (Figure 7). This groundwater divide may shift from OW6-83 to OW13-83 depending on the season. Shallow groundwater flows, therefore is predominantly westward with some minor flow to the east.

In order to assess the permeability of the granular deposits, seven mechanical analyses were performed on split-spoon samples obtained during the test drilling. The results are given in Appendix C, which indicates that the average coefficient of permeability in the sand is 1.5×10^{-2} cm/s.

Using the groundwater gradient for the November 29, 1983 measurement (Figure 7), it is calculated that the average groundwater velocity in the surficial sand is 36 m/a. This depends on the season which may to some degree influence the groundwater gradient.

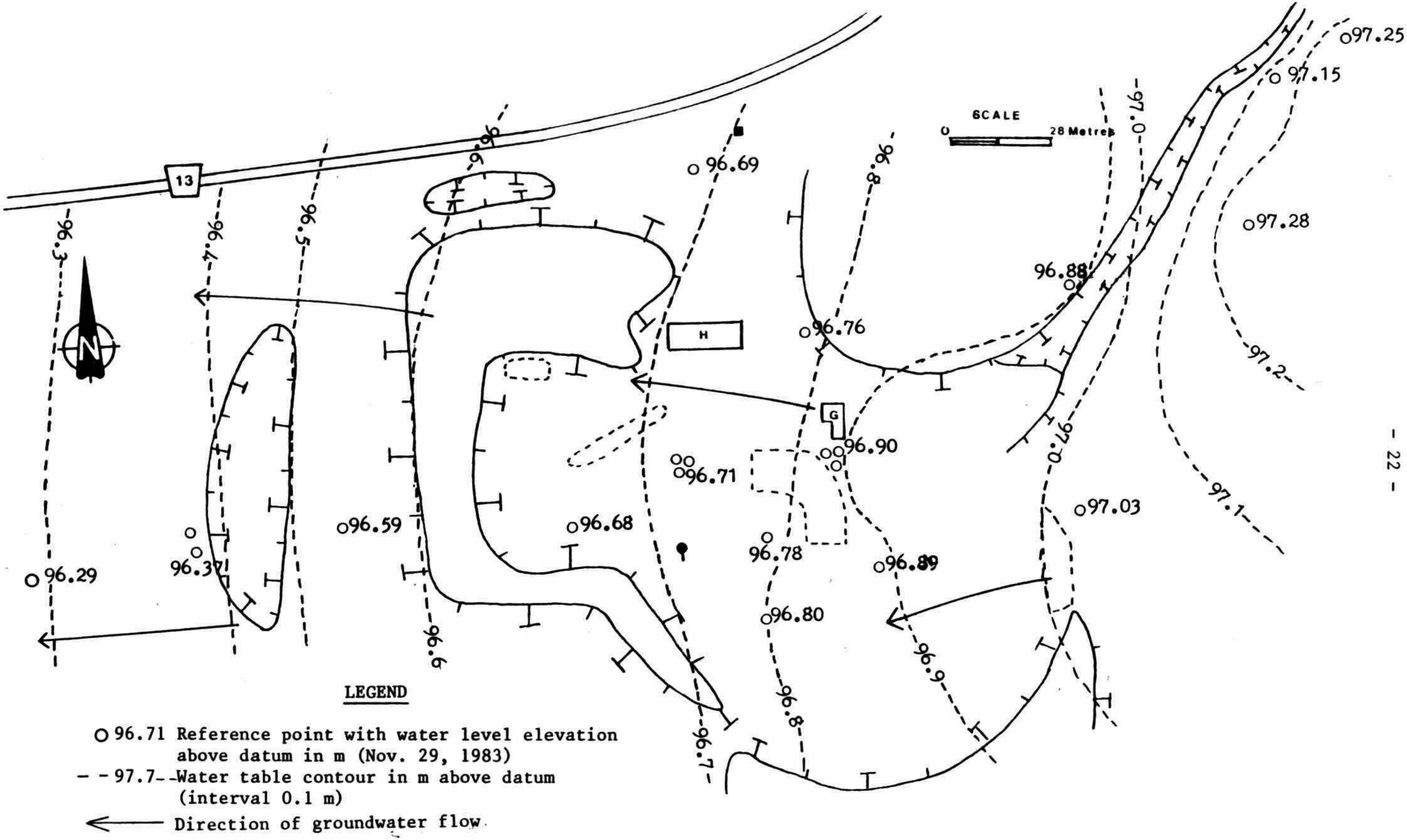


Figure 7. Water table configuration map.

DESCRIPTION OF WASTES

Origin of Wastes

Following the discovery of the presence of the buried drums containing industrial waste in the Field sand pit in late April, 1983 an investigation into origin and source of this waste was undertaken by the Special Investigations Unit of the MOE Southwestern Regional Office. The result of this investigation indicated that waste was generated by a local industry during a standard metal grinding process for production of automotive parts. During the grinding process, a Cimperial 20(trade name) oil was continuously applied with two purposes: (a) as a lubricant and (b) for cooling. This operation produced a waste which can be described as metallic grinding dust, which contained approximately 80% solids saturated with 20% oil.

This waste was placed into 45 gallon drums, covered and wrapped with only green garbage bags at its opened end. On an average 2 to 3 drums of waste were reportedly generated per week. A local waste handling contractor had a contract with the waste generator for the removal and disposal of the drums at "a suitable landfill site". It turned out that these waste-containing drums were taken and buried into the sand pit in 1977.

Chemical Characterization of Wastes

Prior to and during the clean-up operation waste samples were sent to the MOE Laboratory Organic Trace Contaminants Section of the MOE's Laboratory Toronto for analyses. Based on the physical appearance there were two types of wastes:

1. Metallic grinding sludge originally saturated with oil but now relatively dry,

2. Liquid waste with petroleum hydrocarbon or paint solvent odour.

The analytical results performed on waste samples are provided in Appendix F. However, the major characteristics are described in the following paragraphs.

Metallic Grinding Sludge

The samples were leached using the MOE November, 1982 leachate procedure. The major leachate characteristics are:

- Based on the value for specific conductance, a significantly low dissolved solids content.

- Presence of heavy metals were within the drinking water criteria as established by the MOE.

- pH values vary between 5.3 and 9.

- Phenolic compounds and dissolved organic carbon (DOC) levels elevated (highest value for phenol was 72 ug/L, and 264 mg/L for DOC in the waste leachate).

It should be noted, however, that phenolic compounds in groundwater beneath the buried wastes were found in much greater concentrations than in the leachate (550 ug/L of phenols). This is mainly because the liquid portion of the metallic grinding sludge with relatively high concentrations of phenolic compounds had already leaked into the subsurface. In addition, liquid waste which partially

leaked from several drums containing paint solvent had likely contributed to groundwater contamination and the increased phenolic compounds.

Liquid Waste

Samples from five of the drums containing liquid wastes that were recovered from the central portion of the Field sand pit (Area 1 in Figure 2) were collected and analysed for chemical characterization. They were described by the Provincial Analyst as follows:

> "The oily wastes generally found to originate from paint solvents (VM&P naphtha HiSol (high aromatic solvent mixture)), lesser extent from degreaser solvents as medium boiling range petroleum distillates (as stove oil or kerosene) and some chlorinated solvent as 1-1-1 trichloroethane" (Appendix F).

In addition, analytical results on a sample obtained from a leaking pink coloured drum recovered from Area 4 (Figure 2) during the Phase II of the clean-up operation showed the following characteristics as described by the Provincial Analyst:

> "It...was found to contain a mixture of xylenes as organic solvent mixed with smaller amount of higher boiling petroleum hydrocarbons and some amber coloured viscous liquid which was characterized as styrene or vinyl toluene modified alky resin" (Appendix F).

Physical Setting of Buried Wastes

In order to more precisely outline the areas of buried wastes, a geophysical survey employing the magnetometer was successfully carried out on three occasions

Photo 5. Drums containing solid metallic grindings and liquid industrial wastes were piled up at the southern edge of the pit. Drums containing liquid waste had been removed before this photo was taken.
(Photo taken on June 23, 1983)

Photo 6. In addition to the drums, loose waste materials were also encountered in the excavation. The grey/black material (1) appeared to be metal grindings while the orange coloured material (2) was identified by the staff of the originator of some of the waste as the media from a tumbler or polisher.
(Photo taken on June 17, 1983 by Jim McRorie)

(Figure 8). The survey was carried out by staff of the Geotechnical Services, Water Resources Branch of the MOE. A distinctive magnetic anomaly clearly delineated the location of the drummed wastes. Three favourable factors contributed to this success: (a) metallic contents of the drums, (b) the drums themselves were made of metal, and (c) the shallow burial of drums and waste.

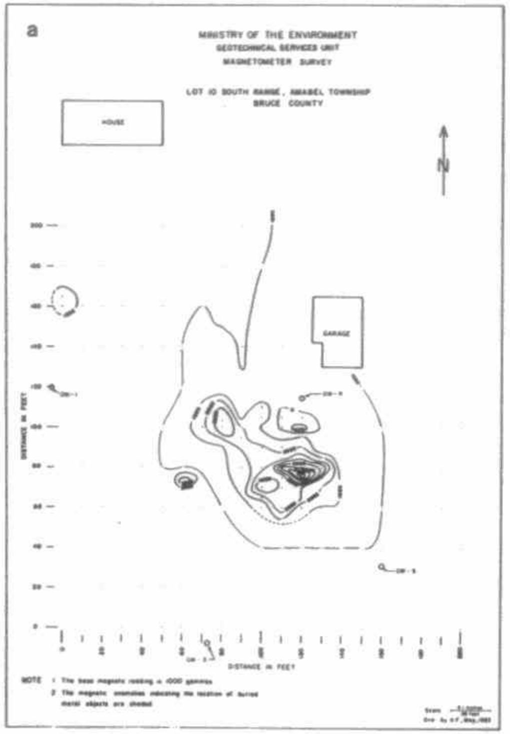
During the recovery and the removal of the drums, it was found that they were placed in an unorganized fashion 0.3 to 1.4 m below the sand pit floor. Because they were laying just above the water table in June, 1983 it is quite conceivable that they were slightly submerged into the water table during the periods of high water table.

The hypsometric position of the buried drums is illustrated in Figures 4 and 5 respectively.

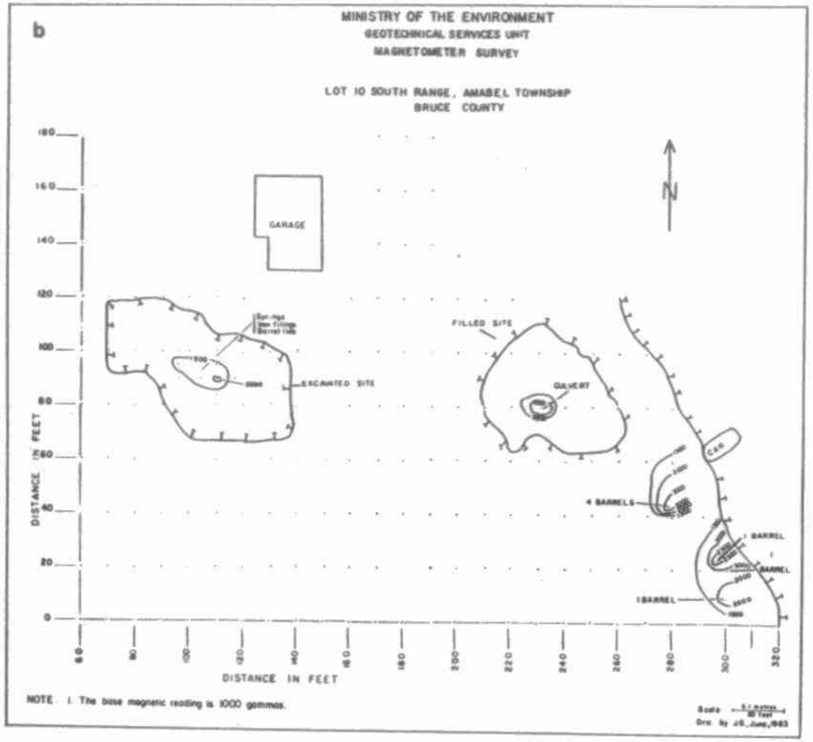
The drums pushed to the east margin of the Field sand pit (Area 2 in Figure 2) were badly twisted and lost most of their content in the process (Photo 2).

By the time of their recovery, the liquid portion from the drums containing the metallic grinding sludge had apparently already leaked into the subsurface. Thus the contents left in these drums was solid but moist metallic grinding sludge.

Several drums containing liquid waste had deterioriated so that they had partially or completely leaked their contents to the subsurface.



Surveyed: 10 May, 1983



Surveyed: 21 June, 1983

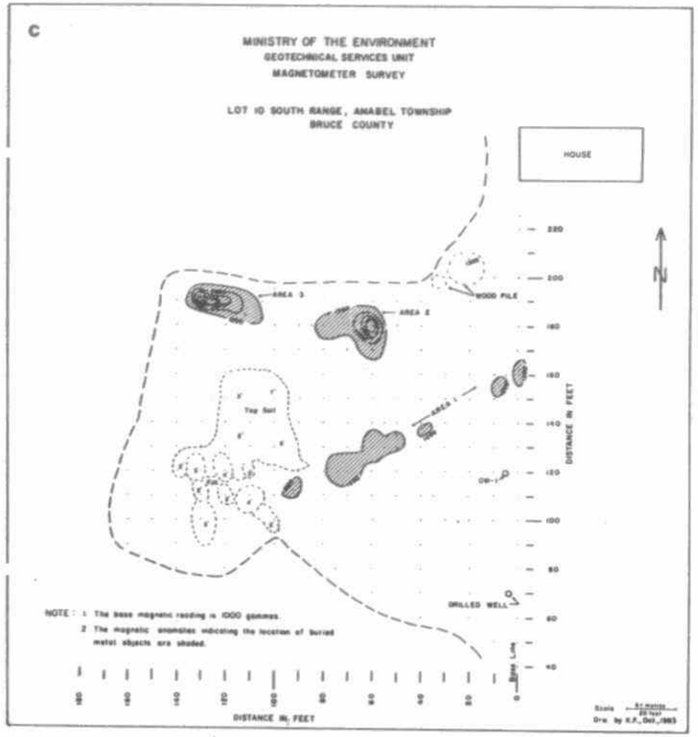


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Figure 8. Geophysical survey maps.

CLEAN-UP OPERATION

General

Soon after the "discovery" that the industrial wastes had been buried in the Field sand pit, it was realized that they were located in a susceptible hydrogeological environment (Whipp, 1982). Therefore, there was some urgency that the clean-up operation be carried out as soon as possible.

Some delay in commencing the clean-up operation was caused by the unresolved question regarding who would pay the direct costs involved. Finally, all participating equipment was hired and paid for by the original generator of some of the waste.

Staff of the MOE participating in the clean-up operation were given the liberty of directing the equipment and having as much waste and contaminated soil removed from the site as they considered necessary.

The clean-up operation was carried out in two phases: Phase I lasted from the middle of June until early July, 1983, and Phase II was done on December 7 and 8, 1983.

During the clean-up operation the following equipment was employed from time to time: small and large size backhoes, small and large size front-end loaders, medium size dump trucks, and vacuum trucks.

Clean-up Procedure

The magnetic anomalies illustrated in Figure 8 were examined during the clean-up process by carefully removing the material sitting above and on the sides of the

drums. Once the drums were uncovered, they were visually and physically checked for soundness and content. After this was determined, extra caution was taken to remove the drums without spilling their contents (Photo 4). This was particuarly important if the content of a drum was liquid waste.

During Phase I of the clean-up operation, drums containing solid waste were piled up in a separate pile from those containing liquid waste. Both piles were located at the southern working face of the Field sand pit (Photo 5). Polyethylene sheets were placed beneath the drums contaning liquid waste in case any of them developed leakage.

There were two reasons for placing and retaining these drums on the pit floor for a short period of time: (a) their contents needed further identification, and (b) an acceptable landfill site had to be chosen for their disposal.

Phase I

The initial clean-up was carried out in Area 1 (Figure 2, Photo 4) from which 170, 45 gallon drums containing metallic grinding dust and 15 drums containing liquid waste were removed. In addition to the drums, loose waste materials were also encountered and removed (Photo 6). Most of the drums were buried just above the water table (1.4 m) and the entire original liquid portion of the drums containing metallic dust had leaked into the subsurface thus contaminating sand and groundwater beneath them (Photo 7).

Before proceeding with the removal of contaminated sand below water table, the second geophysical (magnetometer), survey was carried out. The result of the survey is shown in Figure 8b.

Photo 7. Looking north, a portion of the bottom of the excavation is shown, after the drums and loose waste has been removed. The water table is immediately beneath the floor of the excavation. (Photo taken on June 17, 1983 by Jim McRorie)

Photo 8. Looking north a portion of the temporary pond created by the removal of contaminated sand from beneath the drums is shown. (Photo taken on June 23, 1983)

As the excavation and the removal of sand below water table advanced, a strong odour similar to septage waste was associated particularly with the northern and northwestern bottom of the excavation. Also, during the hot summer days, vapours with the characteristic odour of petroleum products emanated from the excavation. Headaches experienced by a few of the workers were attributed to these vapours.

The average depth of excavation and the contaminated sand removal was 2.4 m. Wooden logs buried by natural geological events approximately 5,000 years ago were found at the bottom of the excavation near observation well No. 4 (OW4-83). Approximately one-metre-deep pond water with very thin petroleum hydrocarbon sheen was created by the removal of contaminated sand (Photo 8). Several volumes of pond contents were pumped using vacuum truck and taken to the originator's of some of the waste treatment facility. During this water removal process, water samples were taken from analyses in order to assess the effectiveness of the clean-up operation. The excavation was finally backfilled with the clean local sand on July 4th and 5th, 1983.

In area 2 (Figure 2) the total of 34 drums were recovered. These drums were badly deformed, squeezed and squashed and some of them half empty. All the excavated contaminated sand along with some loose metallic grinding sludge were taken to the Amabel Township solid waste disposal site. At this site which is located 2.6 km due south, this material was spread in a layer of approximately 0.1 m thick, thus allowing any petroleum product to freely evaporate into the air.

All drums together with heavily contaminated sand were taken by Tricil Waste Management for disposal at their site near Sarnia.

A rough calculation indicated that during the Phase I of the clean-up operation, a total of 585 m^3 of contaminated sand including waste and drums and 204 m^3 contaminated water were removed from the Field sand pit.

Phase II

Background

During the two previous geophysical surveys carried out on May 10, 1983 and June 21, 1983, the western portion of the Field sand pit was not included. This is the area located west of OW1-83 (Figure 2). The main reason for not including it was that at that time, there was a stockpile of topsoil up to 2.1 m high in that area.

During the summer months of 1983, as the demand for the topsoil increased, large volumes of this topsoil were removed. As a result of this, a significant area of the original sand pit floor was revealed. Concommitently, it was discovered that a narrow strip of the pit floor elongated in the northeast-southwesterly direction was "covered" with the metallic grinding waste. Two shallow test pits excavated on August 17, 1983 revealed that this layer of metallic grinding sludge was up to 0.3 m in thickness.

A third geophysical (magnetometer) survey of this portion of the Field sand pit was carried out in this area on October 18, 1983 when there was a relatively small volume of topsoil still left on the sand pit floor. The results of the geophysical survey are shown in Figure 8c. Basically, three magnetic anomalies were revealed suggesting that an additional clean-up operation was necessary.

The area located immediately southwest of the actual sand pit (across the natural "dyke" from OW3-83, OW11-83 and OW14-83 in Figure 2) was briefly checked for the possible presence of buried waste. Two insigificant magnetic anomalies were found to be caused by a metal road culvert and other scrap metal pieces.

The delays in carrying out Phase II of the clean-up operation were mainly caused by: (a) legal arrangements between two of several parties involved, and (b) agreement on who was going to pay for the direct cost of the clean-up.

Actual Clean-up Process

This phase of the clean-up process was carried out on December 7 and 8, 1983. A detailed account of Phase II is provided in an interim memorandum by Novakovic (1984) and Exhibit A of this report

Basically, all magnetic anomalies shown in Figure 8c were examined during the clean-up process.

In Area 3 only one 45-gallon drum containing solid metallic grinding dust was recovered. A significant volume of loose metallic grinding sludge was removed. This material had a typical septic waste odour - the same odour which was found to be associated with waste and contaminated sand excavated during Phase I of the clean-up operation in Area 1 (Figure 2).

In Area 4 two drums (pink and green) containing liquid waste (paint solvent) were recovered. Portions of the contents of the green coloured drum had already leaked into the subsurface. The drum content was transferred into sound drums and taken from the site on the same day by the originator of some of the waste (Photo 9).

Photo 9. Liquid waste from the pink drum being transferred to a sound drum brought in for this purposes by the generator of some of the waste.
(Photo taken on December 7, 1983)

Photo 10. Looking northwest, the completed cleanup areas 3, 4 and 5 are in the northwestern section of the Field sand pit. The absence of snow delineates the extent of the clean up.
(Photo taken on December 8, 1983)

Besides the drums, a significant volume of metallic grinding waste found in the sand and the heavily contaminated sand was excavated and removed. In this clean-up area, a relatively deep pit was excavated into the water table (2.8 m) and water samples were taken and submitted for analyses. Odour characteristic of petroleum hydrocarbon emanated from the excavated sand and from the pit.

A total of eight drums, two containing liquid waste and six containing solid metallic grinding sludge were removed in Area 4. This brought the total of 228 drums recovered in the Field sand pit.

The area indicated as "wood pile" in Figure 8c was also examined by excavating to one meter in depth. No waste drums were found here; only pieces of scrap metal.

The clean-up process in Area 5 was completed by excavation to a maximum of 0.5 m. Each excavated area was backfilled with clean sand and then graded (Photo 10).

Because additional lugger buckets were not available at the site, the contaminated sand and some loose waste mainly from excavation area 5 were initially stockpiled immediately southwest of Area 4 (Photo 10). By December 19, 1983 all excavated sand, waste, and drums were taken from the pit by Tricil Waste Management Limited for disposal at their site near Sarnia. This amounted to the total of 86 m^3.

At the end of Phase II of the clean-up operation, the total of 228, 45-gallon drums were recovered of which 17 contained liquid waste (paint solvent) and 211 contained solid metallic grinding sludge. Furthermore, a total of 694 m^3 of contaminated sand, loose waste, and drums

containing solid grinding sludge and 204 m^3 of water were removed from the Field sand pit.

WATER QUALITY ANALYSES

General

In order to assess the existing and possible impact on water quality from the buried industrial waste in the Field sand pit, and to establish background water quality in the general area, a number of water samples from various sources were collected and analysed for various parameters. These sources include: domestic water wells, communal wells, cottage water wells, a recreational well point, observation wells, pond water resulting from clean-up operations, surface water and runoff. The results of these analyses are summarized and given in Appendices G through K inclusive.

Some selected constituents are plotted and shown in Figures 9, 10, 11 and 12.

Sampling Procedure

Nine water supply wells were sampled at least once between April 1983 and the time of writing this report. Water samples were obtained from kitchen taps. The locations of groundwater sampling points are given in Figures 2 and 3.

A special sampling procedure was used while sampling observation wells. Depth to water level in each well was measured first. Prior to taking water samples from an observation well one to four casing volumes of water was removed in order to obtain fresh formation water. This was

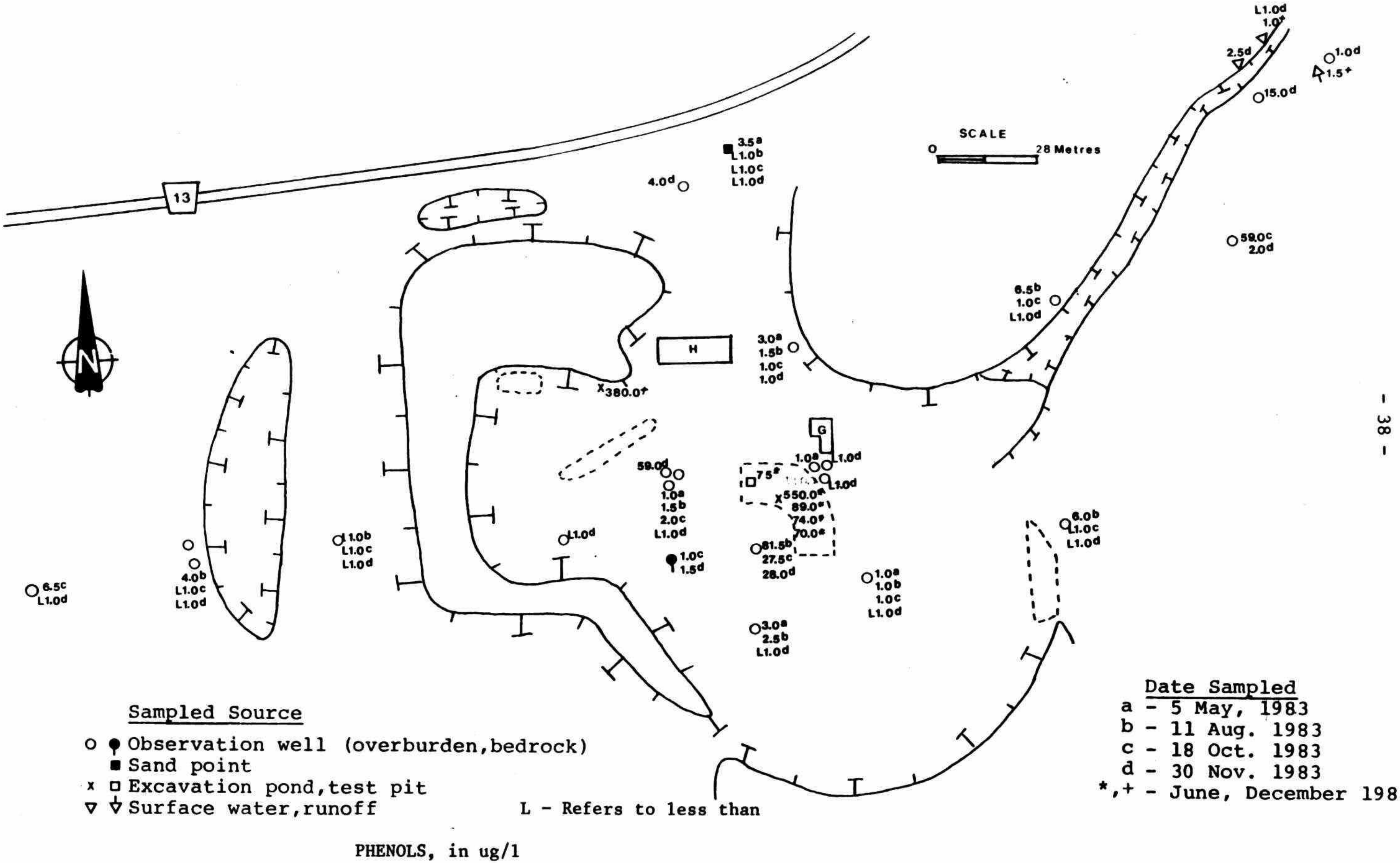

Figure 9. Hydrochemical map of phenolic compounds distribution in groundwater and surface water systems.

done using a gasoline powered pump. A flexible garden hose was lowered inside the well casing and the amount of pumped water was carefully measured. Before inserting the garden hose into the well casing the hose was washed with distilled water.

Following this procedure and after the water level recovered, samples were obtained using a single bailer. If the same bailer was used to sample more than one well, the bailer was rinsed with distilled water to avoid cross-contamination.

This sampling procedure was repeated each time the samples were collected.

All groundwater samples obtained from observation wells, were filtered in the laboratory using 0.45 micron filter paper.

Groundwater Quality

Groundwater quality analyses obtained from three different sources are discussed separately. These include: water supply wells, observation wells, and excavation ponds and test pits.

Water Supply Wells

A total of nine water supply wells were sampled and analysed for background water quality. Their use varies from domestic (5), cottage (2), and recreational (1) to communal (1). The location of the sampled wells is shown in Figure 3 and the summary of chemical analyses for these wells is provided in Appendix G.

Water quality in these wells varies, reflecting the natural geological environments from which these wells obtain water. For example, bedrock wells (Cammidge/Collins subdivision, J. Good and B. Patterson) are extremely low in sulphate (less than 0.5 mg/L), chloride (1.5 mg/L) and sodium (up to 4.0 mg/L) content. It should be noted though, that the B. Patterson bedrock well has experienced contamination (high free ammonia nitrogen) from a source yet to be established.

Water quality in several shallow sand points also reflect the depositional environment of the utilized aquifer. Here, the presence of organic matter and other substances cause the somewhat elevated concentrations of iron, phenolic compounds and dissolved organic carbon in several shallow sand points.

In general, however, with few exceptions, all parameters for which water samples were analysed were within the Provincial Drinking Water Objectives.

Bacteriological quality results indicate that water was suitable for human consumption in the Field water supply source at the times of sampling (Appendix H).

Observation Wells

A total of 22 observation wells were installed on the Field and two adjacent properties. They were sampled on several dates and the results of water quality analyses from these wells are summarized in Appendix I. Selected parameters for the selected sampling dates are plotted in Figures 9, 10, 11 and 12.

Water quality in observation wells was typical for the shallow sand aquifer with occasional slightly elevated

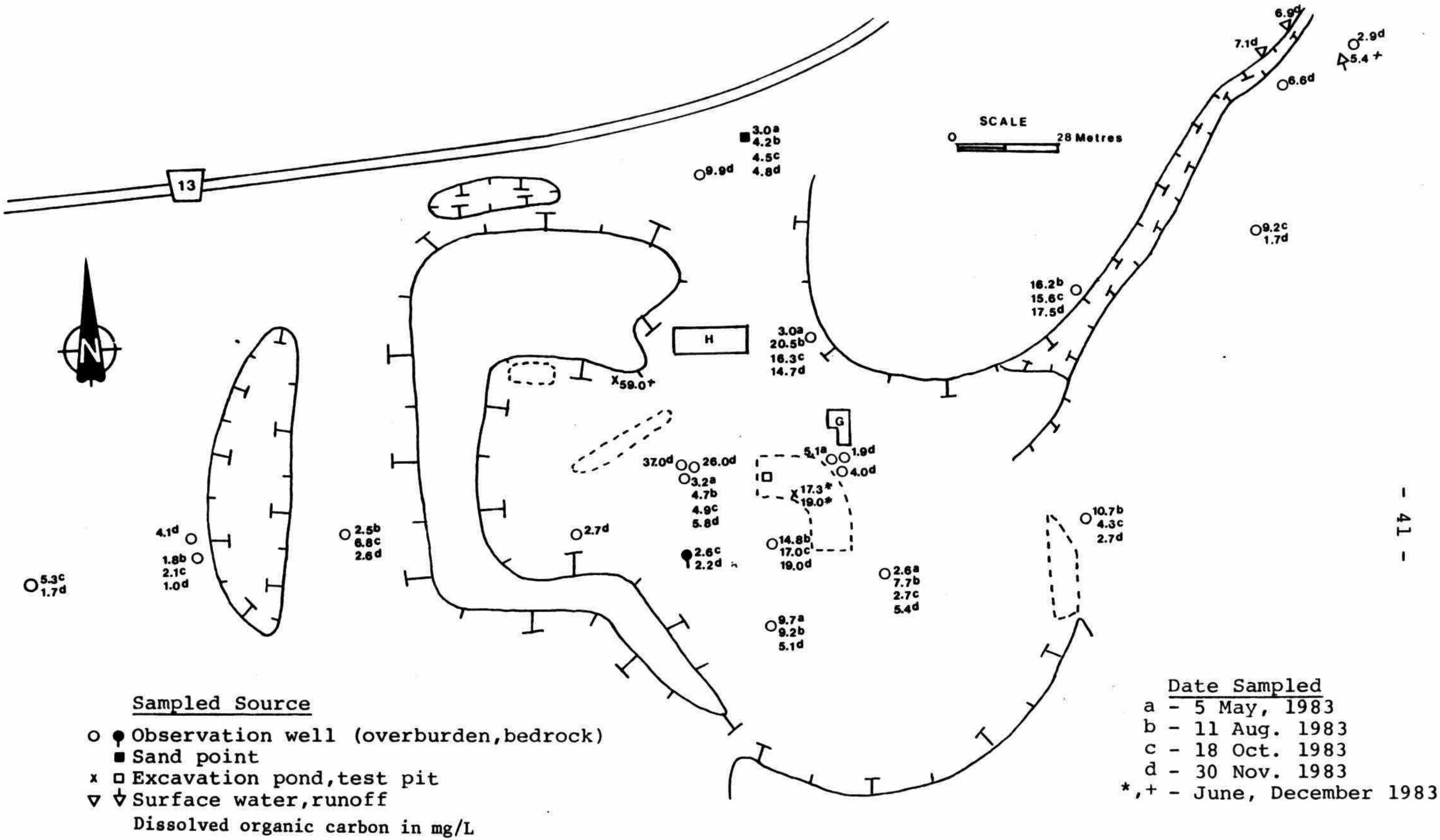

Figure 10. Hydrochemical map of dissolved organic carbon distribution in groundwater and surface water systems.

content of dissolved organic carbon, iron and phenolic compounds. This would be expected to occur in a similar geological environment.

The exception to this general trend of groundwater quality in the surficial aquifer is the area immediately west of the clean-up area 1 on the Field sand pit. Using contamination indicator parameters such as phenolic compounds, dissolved organic carbon, and chloride the following findings are made:

1. There appears to be a general increase in these parameters in several observation wells located immediately west of the clean-up area 2. These include the following observation wells: OW1-83, OW1b-83 and OW9-83.

2. These increases are in concert with the direction of groundwater flow.

3. Groundwater as a transporting agent of the contaminants along with geological factors have dictated the depth and lateral extent of the contamination plume generated by buried wastes.

4. It is apparent that the sources of this plume were industrial wastes buried and left for some time in the Field sand pit (mainly clean-up area 2).

5. The contamination plume is confined within a relatively short distance due west from clean-up area 2. The front of contamination is believed to be located between OW1-83 and OW14-83 observation well nests.

6. Based on the available information, only a few parameters such as phenols, and dissolved organic

carbon in the plume exceed the drinking water objectives. Also, possible taste and odour concerns from the presence of petroleum products within the plume area might contribute to the rejection of groundwater in this area as a source of drinking water.

7. Outside of the contamination plume, a few wells exhibited increased concentration of phenols or believed to be dissolved organic carbon on a few occasions. This is due to natural occurrences in combination with possible cross-contamination. For example, OW2-83 and OW10-83 have consistently shown elevated dissolved organic carbon which is due to the presence of organic deposits near the perforated portion of the piezometer (intake). Similarly, OW8-83, OW12-83 and OW13-83 reported elevated levels of phenols on the initial sampling date. Considering that these three monitoring wells were not developed after construction and before initial sampling, it is quite conceivable that phenols were the result of cross-contamination which may have occurred during their installation.

   It is significant to note that the results of water quality analyses for OW1-83 (shallow well sampling the very top of the saturated zone) did not have any significant levels of phenolic compounds. Subsequent installation and sampling of two deeper observation wells at this location, a part of the same piezometer nest, showed relatively high levels of phenols and DOC. This suggests that the contamination plume was initially missed by sampling of the very top of the saturated zone, thus giving initially a somewhat unrealistic picture of the existing situation.

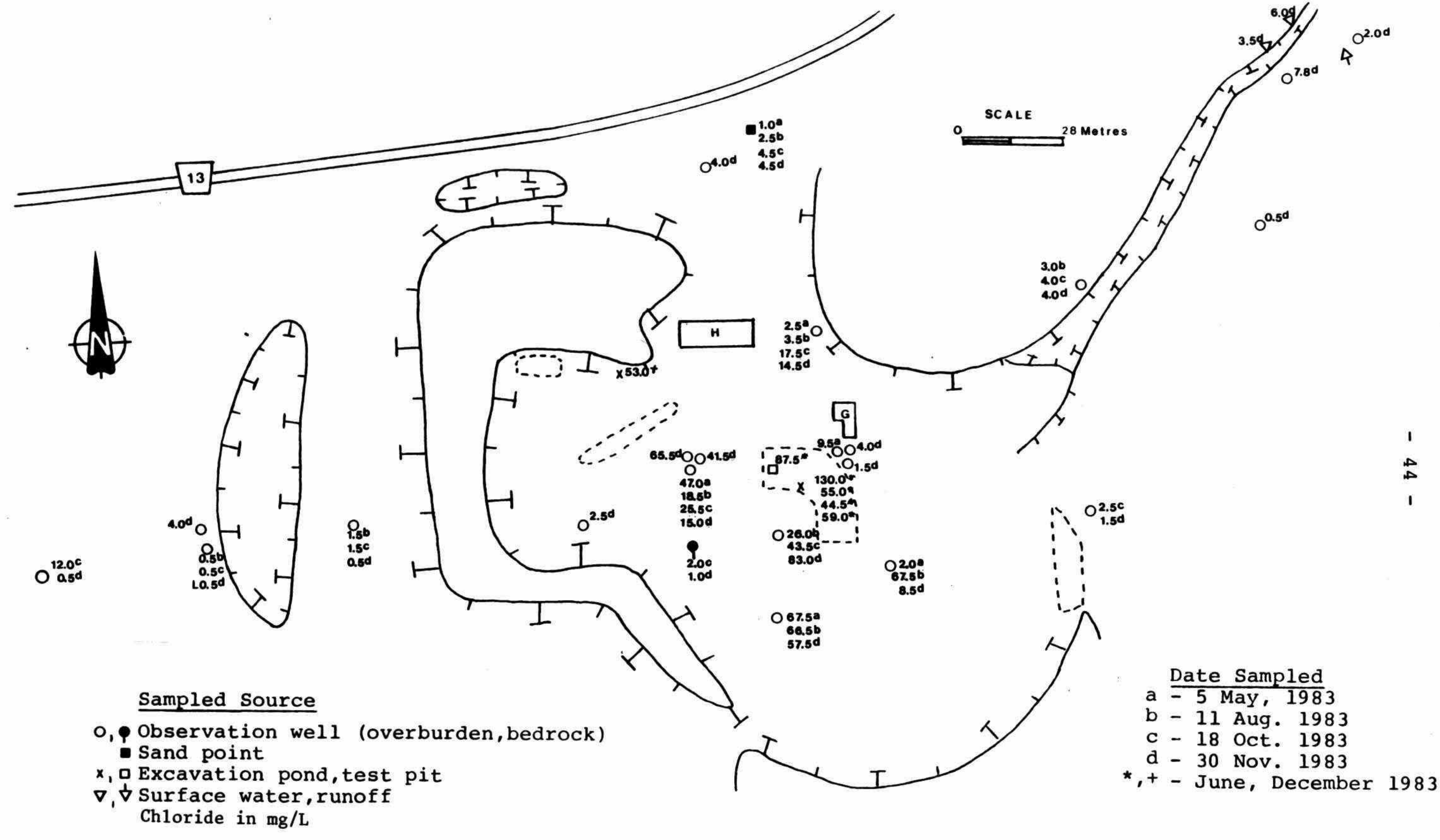

Figure 11. Hydrochemical map of chloride distribution in groundwater and surface water systems.

8. It is considered that the subsurface sand and water contaminated by buried industrial waste in clean-up area 4 is confined to a zone beneath and a short lateral distance from that area. There is no indication that plumes associated with two clean-up areas (1 and 4) are already connected.

9. Wastes in three other clean-up areas (Nos. 2, 3 and 5) had apparently not generated any significant contamination plume.

Excavation Ponds and Test Pits

In the course of the clean-up operation, water table of the shallow aquifer was revealed in clean-up areas 1 and 4 respectively (Photo 8). Water samples were taken from both of the temporarily created ponds and the results of these analyses are given in Appendix J.

Relatively high phenols and dissolved organic carbon contents were found in the initial samples in both ponds (excavation area 1: phenols 550 ug/L, DOC 173 mg/L, excavation area 4: phenols 380 ug/L, DOC 59 mg/L). These phenol levels far exceed the Ontario Drinking Water Objective of 2 ug/L.

There is no doubt that the contaminants found in groundwater were the result of the industrial waste buried at the two locations.

After the clean-up process was completed in area 1 which involved significant water pumpage from this pond, the phenol content was reduced to 74 ug/L and DOC was reduced below 19 mg/L.

It is also noted that components of the nitrogen cycle such as free ammonia (10 mg/L), total Kjeldahl (3.5 mg/L), nitrite (0.103 mg/L) and nitrate (8.35 mg/L) were elevated in the pond in clean-up area 4.

It is significant that the nitrogen concentrations found in a groundwater sample taken from the pond in area 4 is two times higher than the nitrogen content found in the pond (groundwater) in Area 1 resulting from the removal of drums and contaminated sand during Phase I of the clean-up operation at this site (June and July 1983). It is conceivable that septic tank tile discharges which are located a short distance from the clean-up area 4 have contributed to these increases of nutrients in the local groundwater (Novakovic, 1984).

A water sample from the pond in clean-up area 4 was also analysed for heavy metals. Very slightly elevated levels of manganese, iron and lead were found, but this may be due to the natural causes. Other heavy metals were well within drinking water criteria set for communal water.

Surface Water Quality

Water samples were collected from surface water sources at four locations on November 30, 1983 (Appendix K). Earlier collection of surface water samples was not possible from the northeastern portion of the Field property (low area which is periodically covered with water) and from the ditch on the adjacent property because there was no water.

The analytical results of the two water samples collected from the ditch (sampling location Nos. 1 and 2) indicated that the water was typical for surface water originating from an area rich in natural organic matter (slightly elevated concentrations of DOC and phenols).

The same is true for the ponded water at OW16-83 which also had slightly elevated concentrations of DOC and phenols. The analytical results of the two water samples taken from the Patterson property (ditch and swamp) southeast of the Field property (Figure 3) are typical for swamp water and quite similar to water quality on the Hackett property.

It is significant to note that analyses of murky water taken from one of the drums lying east of the Field's garage had relatively high concentrations of phenols (86.5 ug/l) and DOC (54 mg/L). There was no evidence to suggest however, that spillage from these drums had taken place.

DISCUSSION

General Considerations

Metallic grinding sludge mixed with approximately 20 percent of lubricating and cooling oil (C Imperial 20) was placed into 45-gallon drums, wrapped with green plastic garbage bags around the opened end of the barrels and then disposed of by being buried in the Field sand pit about 1977.

Seventeen drums containing paint solvent were also buried with drums containing solid waste.

Some Factors Affecting the Extent of Subsurface Contamination

Field work such as (a) a test drilling program, (b) excavation of test pits, (c) aquifer clean-up operation involving removal of drums, loose waste, contaminated sand and contaminated water, (d) water level measurements

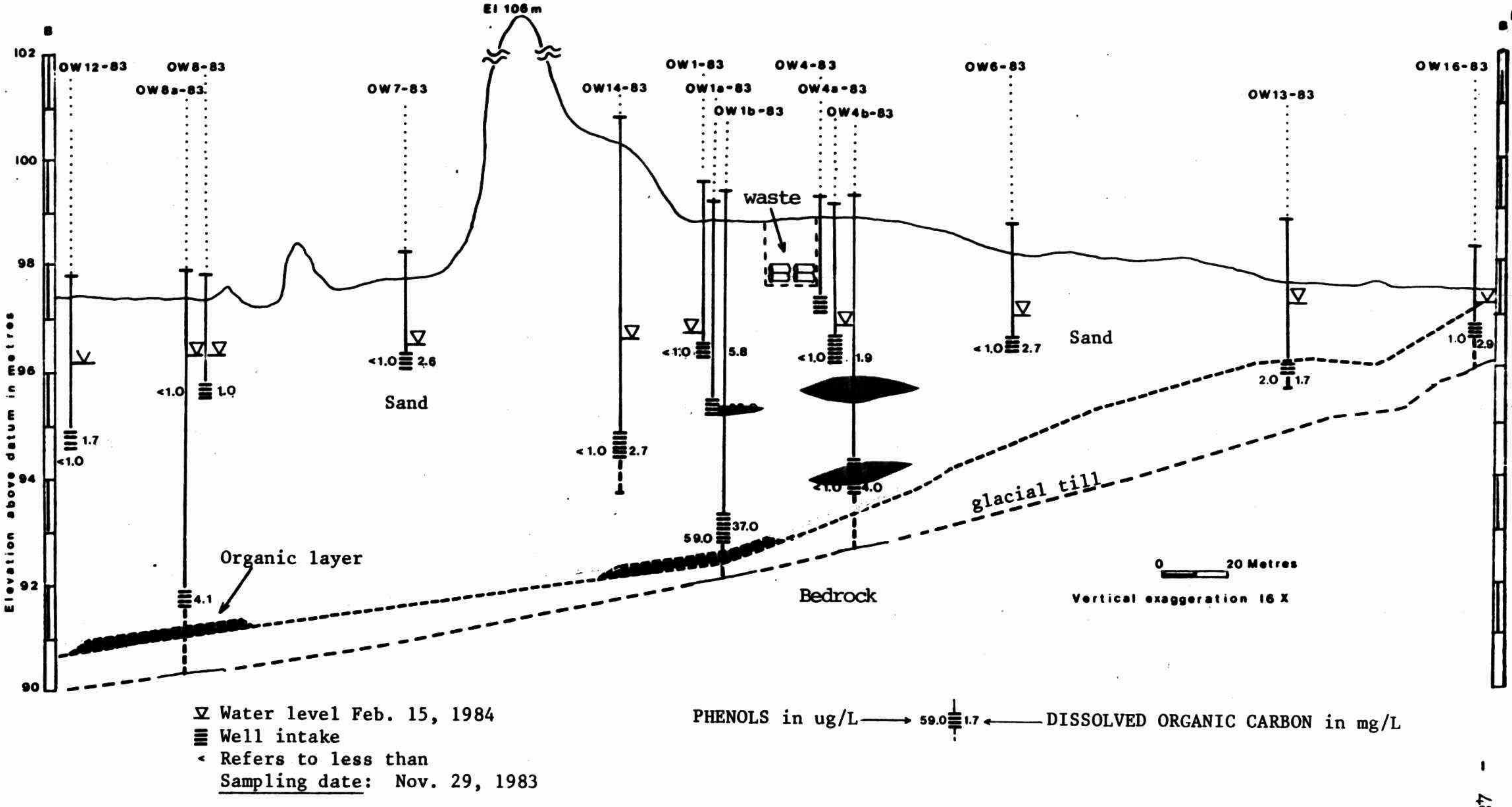

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Figure 12. Concentrations of phenolic compounds and dissolved organic carbon along the cross-sectional plan B-B'

resulting in the delineation of groundwater flow direction, (e) hydraulic parameter calculation, and (f) analytical results of waste, water, and contaminated sand samples enabled delineation of the extent of subsurface contamination.

The depth and lateral extent of the contamination plume is governed by several factors such as:

1. The permeability and hydrogeological characteristics of the underlying subsurface environments.

2. The depth to water level and its fluctuation throughout the year.

3. Attenuating capacity of the subsurface environments.

4. Specific climatological conditions, including the amount and intensity of rainfall, snowfall, temperature, duration of snow melt, etc.

5. Location and type of waste as a potential contamination source.

6. Direction of groundwater flow and velocity.

7. Time factor.

The depth of burial varied between 0.15 m and 1.4 m below the pit floor.

The liquid portion of the metallic grinding sludge and some of the drums of liquid thinners leaked into the subsurface environment. Percolating water from precipitation and groundwater level fluctuations which periodically and partially submerged some of the drums had

both contributed to leaching and subsequent release of several contaminants from these wastes. Phenolic compounds and dissolved organic carbon were the major indicator parameters of contaminant released into the subsurface environment.

Distribution of Indicator Parameters

As indicated in Figure 9 and 10, phenolic compounds and dissolved organic carbons were found in relatively high concentrations in groundwater beneath and immediately west from the buried wastes. In the clean-up area 1: phenols 550 ug/L and DOC 173 mg/L; clean-up area 4: phenols 380 ug/L, DOC 59 mg/L.

Although the contents of drums with metallic grinding waste were quite dry or just moist, at the time of their recovery, factors such as infiltrating water and groundwater fluctuations have influenced periodic leachate release into the subsurface environment. This irregularity may have generated a "pulsatory leachate front" moving in the westerly direction along groundwater flow path.

Occasional and unpredicted increases in leachate strength may have occurred as a result of liquid waste leakage from a drum at some later date after their burial. Rusting, compacting due to the above traffic load and other factors may also have been the cause of increased seepage. There is no doubt based on this investigation that increased phenolic compounds and DOC concentrations found in several observation wells (OW1b-83, OW9-83) were caused by the industrial waste that was buried in the Field sand pit.

The Field Well Point Water Supplies

According to Mr. Frank Field, there were four locations of his water supply well point before moving it to the present and the fifth location. They are indicated in Figure 2 (insert). The former four well point locations existed before the MOE staff got involved in any investigation of the situation. Therefore, no water quality data for the first four locations is available.

However, three observation wells (piezometer nest OW1) with intakes at different depths were installed approximately one metre from the Field's former well point location No. 4 (Figure 2). Observation well 1 (OW1-83) was installed on May 5, 1983 with the piezometer bottom set at 2.32 m which was 0.58 m below water table at that time. Subsequent water quality monitoring did not reveal any significant contamination at this depth. The concentrations of phenols varied during the monitoring period between less than 1 ug/L and 4 ug/L and between 3.1 mg/L and 5.8 mg/L for DOC.

It is important to note that during the development of observation well 1 (OW1-83) done immediately following its construction water in the second 9-litre pail (total of three 9-litre pails of water were pumped) had a very faint "paint-thinner" odour.

Test drilling in late November 1983 at this location for the installation of two observation wells OW1a-83 and OW1b-83 revealed existance of contaminated sand with an odour of petroleum hydrocarbon at depth intervals between 4.5 and 5.5 m.

The result of water samples taken subsequently from these two observation wells confirmed the existence of the contamination plume at depths greater than the reported intake of the former Field well point. It is therefore conceivable that, mainly due to water level fluctuations and pumpage, water quality in this well may have been affected when the Fields were using this well for their domestic supply.

The analytical results of water quality in the present Field well point indicate that water is suitable for human consumption. The water quality is typical for the shallow sand aquifer with occasional slightly elevated phenols, iron and dissolved organic carbon. On several occasions, the levels of iron and phenols were slightly above the Provincial Water Quality Objectives for communal water supply as set by the MOE. These objectives for iron and phenols are based on aesthetic considerations.

Phenols, iron and dissolved organic carbon would be expected to occur naturally in similar geological environments to those present at this location.

RECOMMENDATIONS

Based on the available information and work carried out to date, the following recommendations are made:

1. Water quality monitoring in selected domestic wells and observation wells constructed at and in the vicinity of the Field sand pit should be continued. Monitoring should also include surface water at several selected locations.

2. A decision regarding the need for additional clean-up which may involve the installation of a system of recovery wells to pump contaminated water, for example should be based on the results of the continued water quality monitoring program.

3. An effort should be made to remove the empty drums and empty engine oil containers along with derelict vehicles located east of the Field garage and machine shop. These articles pose no significant threat to the local environment, but could release phenolic compounds, dissolved organic carbon and possibly some petroleum products.

ACKNOWLEDGEMENTS

The clean-up operation was carried out with the assistance of Bill Currie and Jim McRorie.

Field work was carried out with some assistance from Greg Powers and students Scott McFabe and Ed Van Osch.

Bernie Feenstra helped with the identification of soil samples and the interpretation of the unconsolidated sediments stratigraphy.

Many thanks go to Dan Brown, Jim McRorie and John Swaigan who reviewed the report at draft stage and provided valuable comments.

The geophysical survey was done by Keith Fligg.

Mechanical analysis of soil samples were performed by Steve Check.

Assembling of Appendices and drafting was done by Miss Donna Foggo and Jeff Spong.

Continued cooperation by the original generator of some of the wastes is gratefully acknowledged.

All analyses of water, waste and soil samples were performed by the MOE London Regional Laboratory and the Central Laboratory in Toronto.

REFERENCES

Feenstra, B. H. 1984. Personal communication.

Liberty, B.A. and Bolton, T.E. 1971. Paleozoic Geology of the Bruce Peninsula Area, Ontario. Geological Survey of Canada, Memoir 360. 163 p.

Novakovic, B. 1984. Removal of Buried Drums of Industrial Waste - Second Phase, Lot 10, Range South, Amabel Township, Bruce County (Interim Memo to J. Manuel).

Paragon Engineering Ltd. 1979. Snell Road Development (Winskill Subdivision) 38 Lot Subdivision, Lot 49, Concession D, Township of Amabel, County of Bruce Test Drilling Program and Hydrogeologic Assessment (Report, 19 pp).

Paragon Engineering Ltd. 1983. Cammidge/Collins Subdivision Phase II, 11 Lot Residential Development, Hydrogeologic Assessment (Report 23 pp).

Sharpe, D. R. and Jamieson, G.R. 1982. Quaternary Geology of the Wiarton Area, Southern Ontario, Ontario Geological Survey, Map P 2559, Geological Series - Preliminary Map, scale 1:50,000. Geology 1977.

Whipp, D. 1982. Susceptibility of Ground Water to Contamination Wiarton Sheet, MAP S109. Ontario Ministry of the Environment.